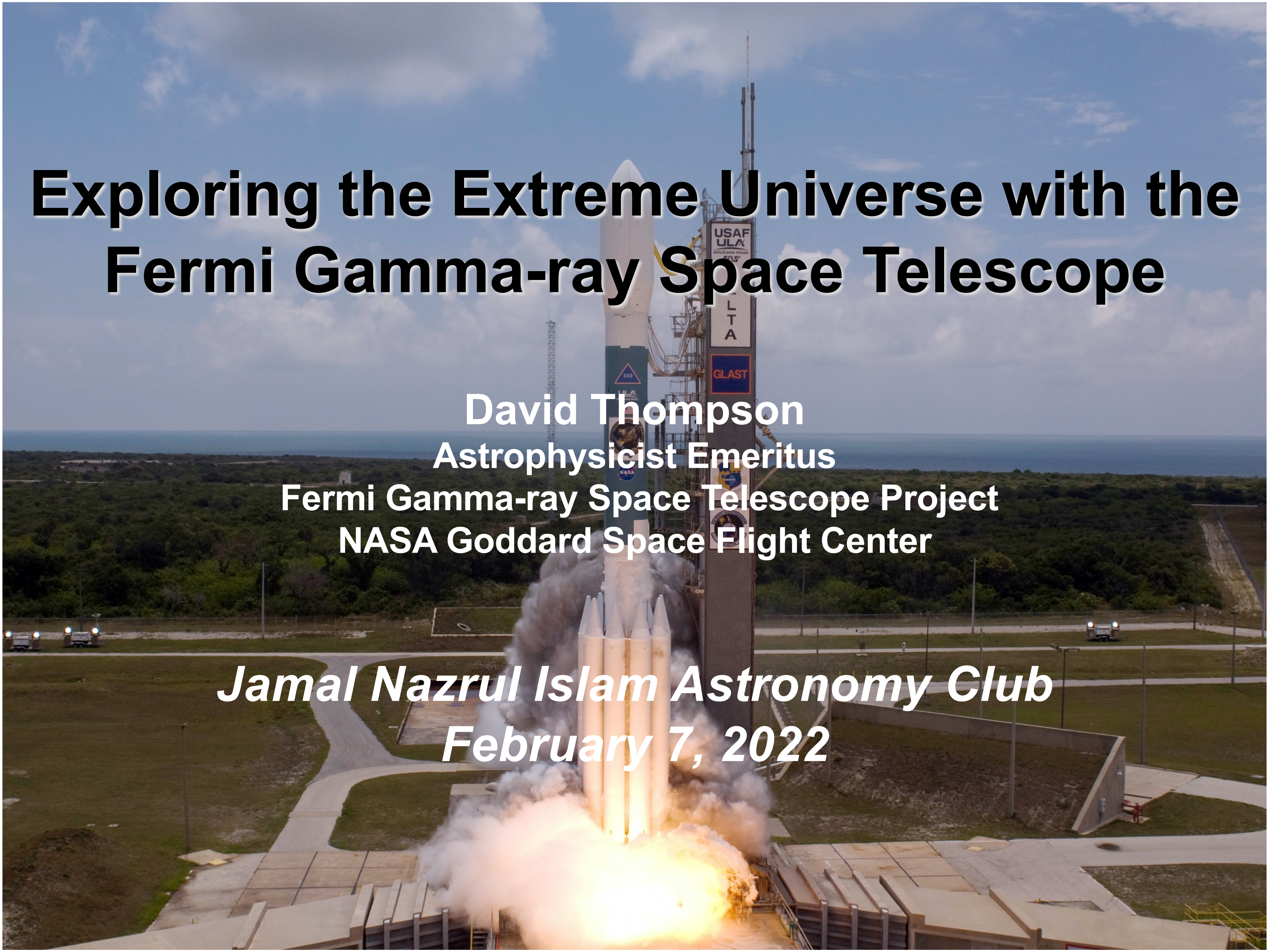

Exploring the Extreme Universe with the Fermi Gamma-ray Space Telescope

David Thompson
Astrophysicist Emeritus
Fermi Gamma-ray Space Telescope Project
NASA Goddard Space Flight Center

Jamal Nazrul Islam Astronomy Club
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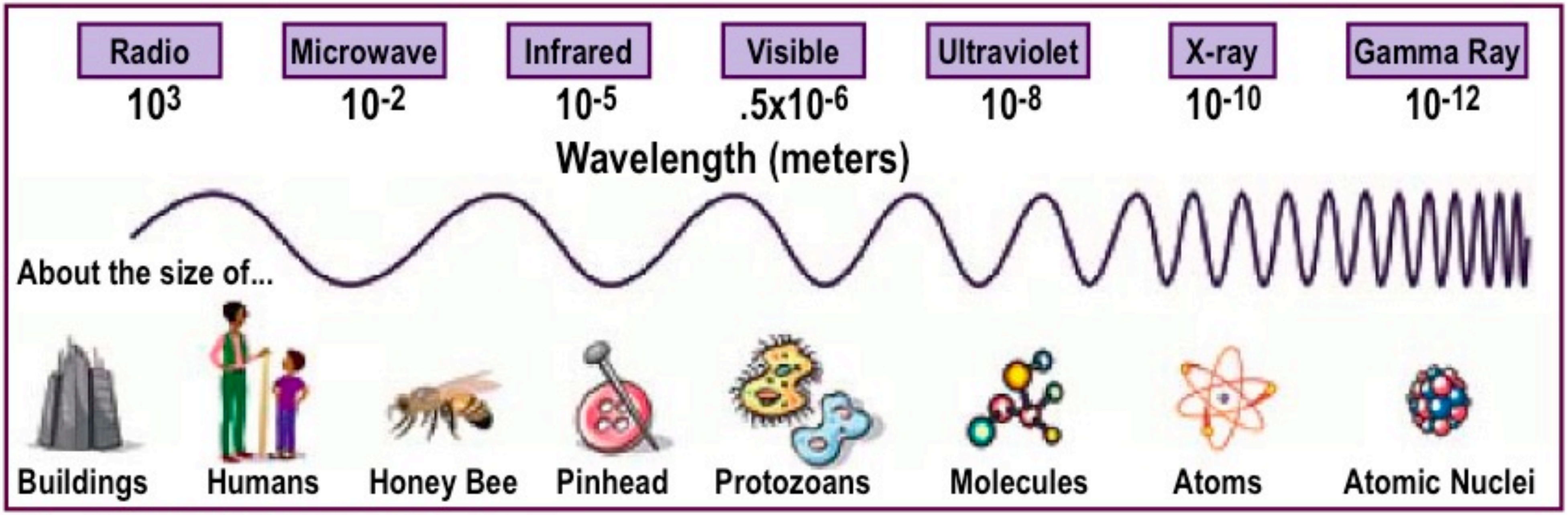
What supposedly first turned David Banner into the Hulk?

Gamma Rays!

Because gamma rays are powerful

What is a Gamma Ray?

One of The Many Forms of Light



Credit: NASA / Ruth Jennings

Each type of light carries different information.

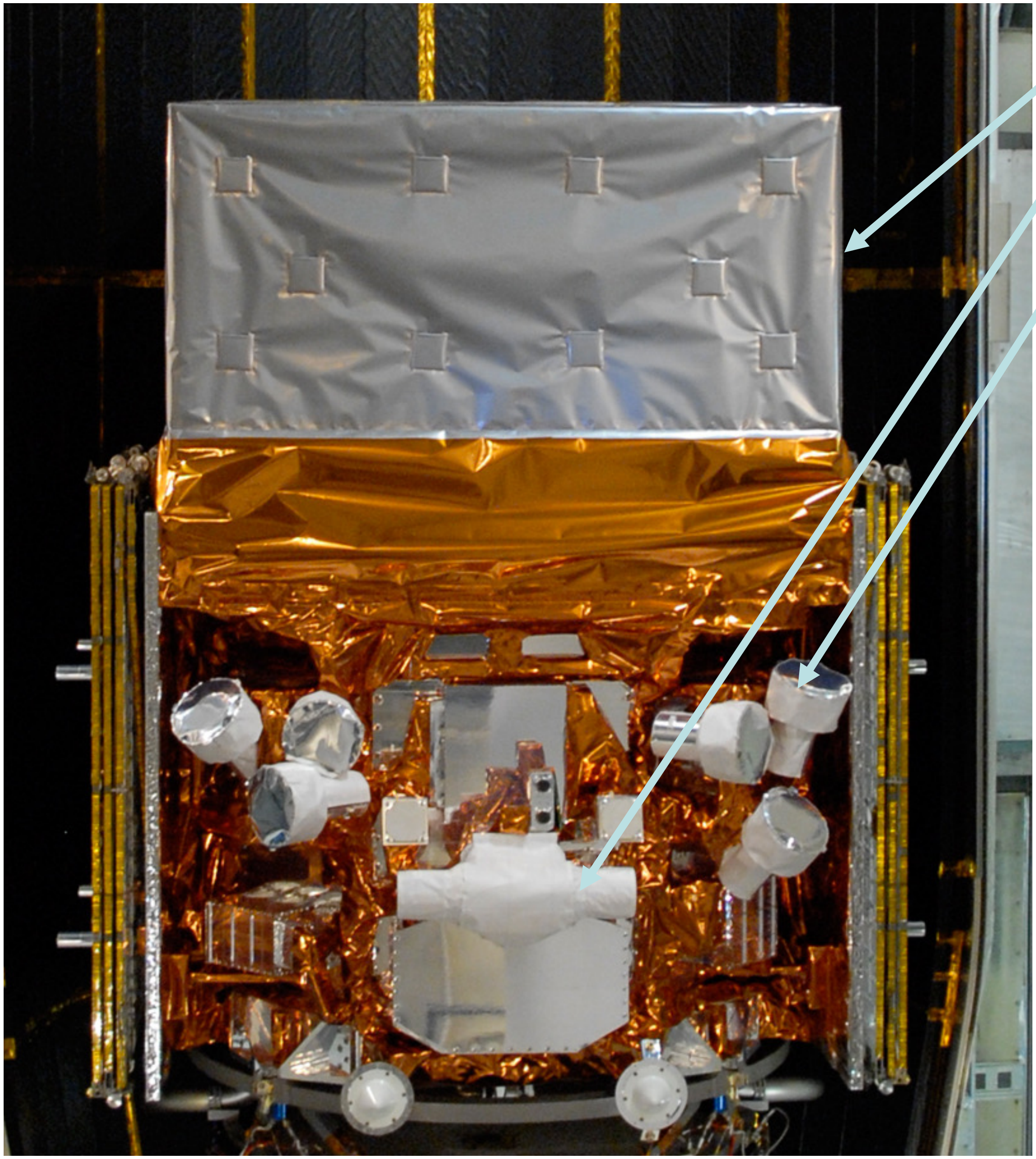
Gamma rays, the highest-energy type of light, tell us about the most energetic processes in the Universe.


But what if you had gamma-ray vision?

The Fermi Gamma-ray Space Telescope

Prior to Fairing Installation

The Fermi Observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

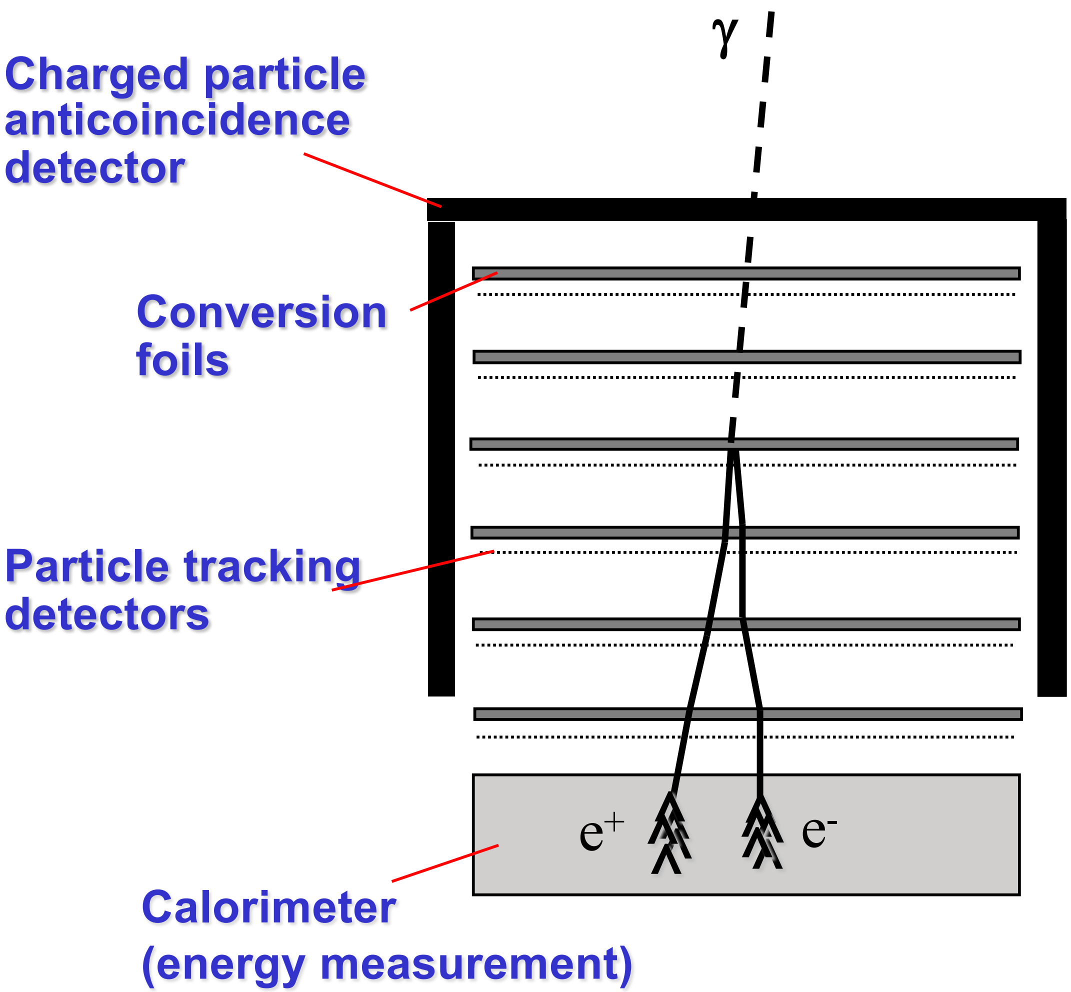
- Huge field of view
  - LAT: 2.4 steradians; 20% of the sky at any instant;
  - GBM: whole unocculted sky at any time.
- Broad energy range.
  - Total of >7 energy decades!
- Every photon can be time-tagged.
  - 1 microsecond accuracy

Launch!

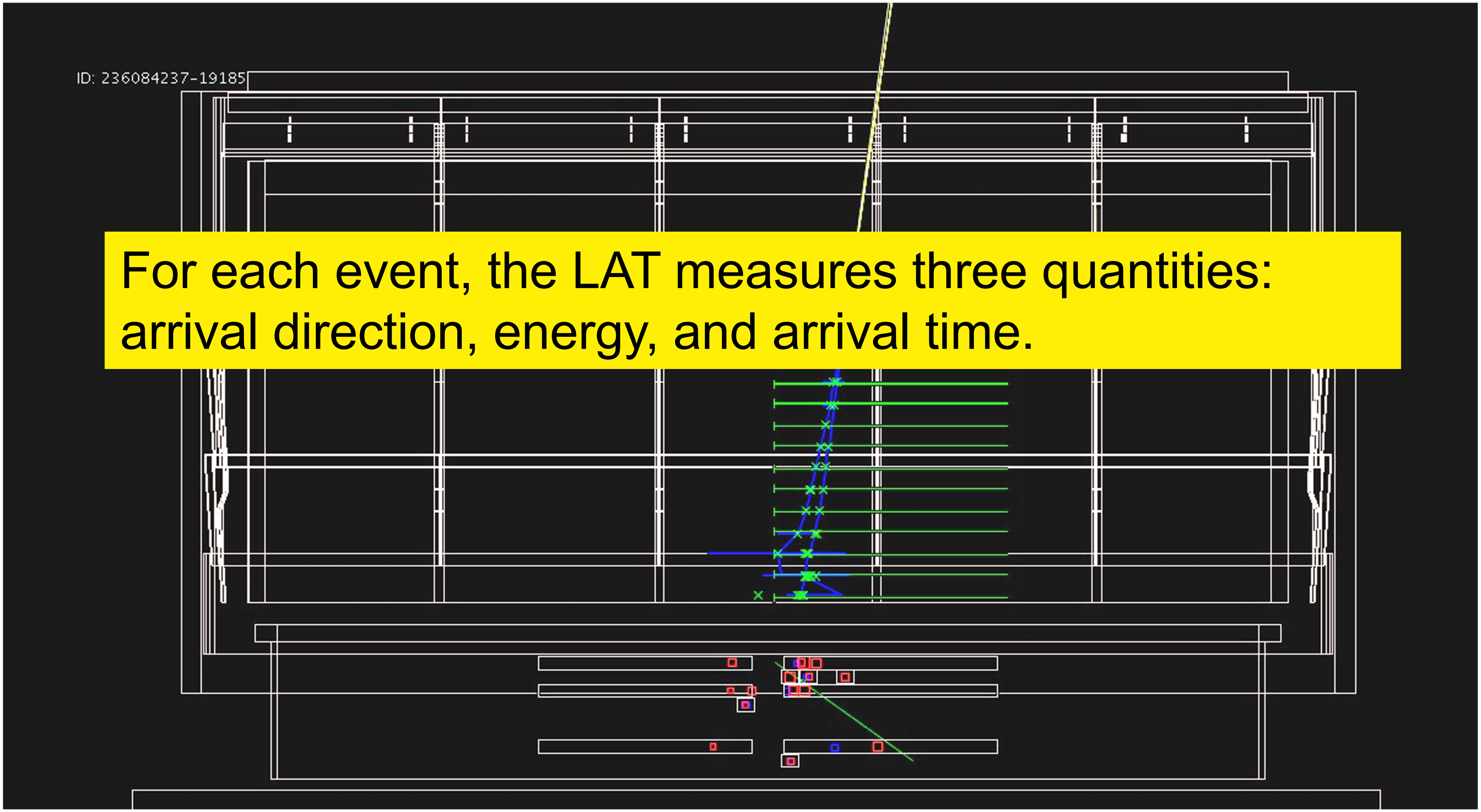
- Launch from Cape Canaveral Air Station 11 June 2008.
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.
- Recently completed 13 years of observations, and the performance is actually better than at launch.

LAT: A Pair Production Telescope
Energies high enough that $E = mc^2$ is important

Principle of Operation



LAT Gamma-ray Candidate Event



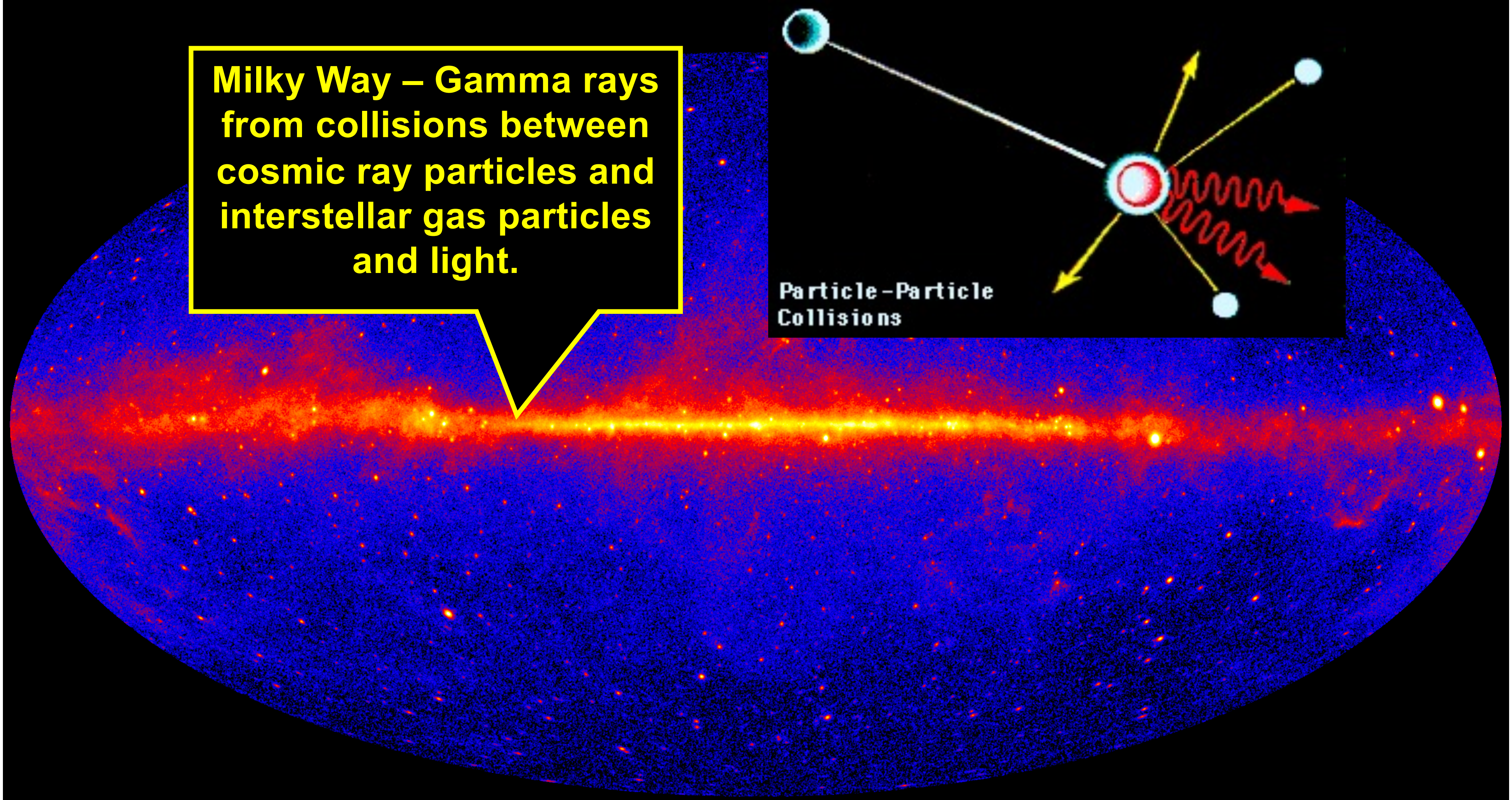
The green crosses show the detected positions of the charged particles, the blue lines show the reconstructed track trajectories, and the yellow line shows the candidate gamma-ray estimated direction. The red crosses show the detected energy depositions in the calorimeter.

How does Fermi operate?

- A key point - because gamma rays are detected one at a time like particles, the *Fermi* telescopes do not have angular resolution as good as radio, optical or X-ray telescopes. Few pretty pictures of individual objects.
- Instead, *Fermi* trades resolution for field of view. The LAT field of view is 2.4 steradians, and the GBM field of view is over 8 steradians.
- The *Fermi* satellite is usually operated in a scanning mode, always looking away from the Earth.
- **The combination of huge field of view and scanning means that the LAT and GBM view the <u>entire sky</u> every three hours!**

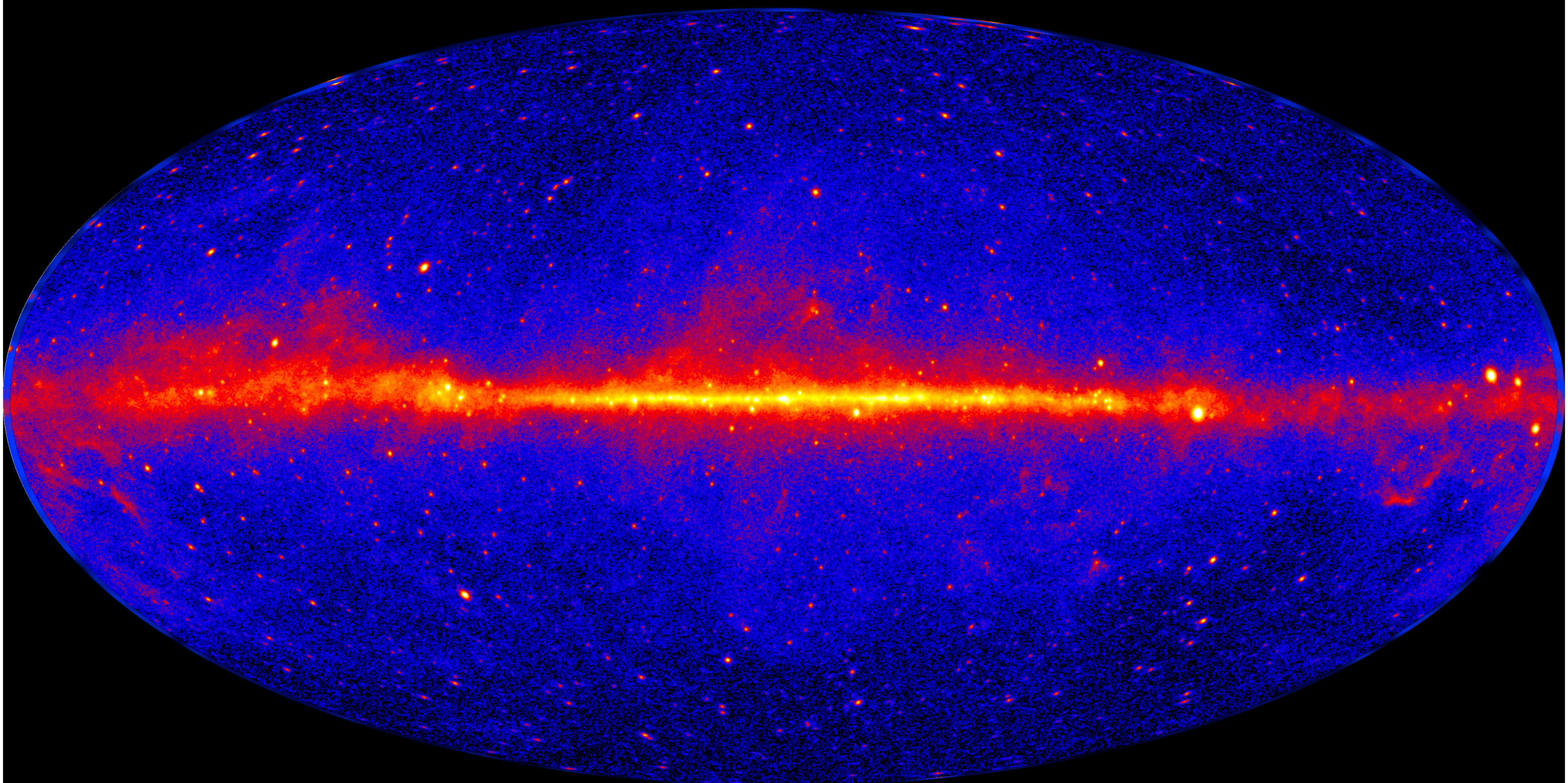
Overview of the Gamma-ray Sky

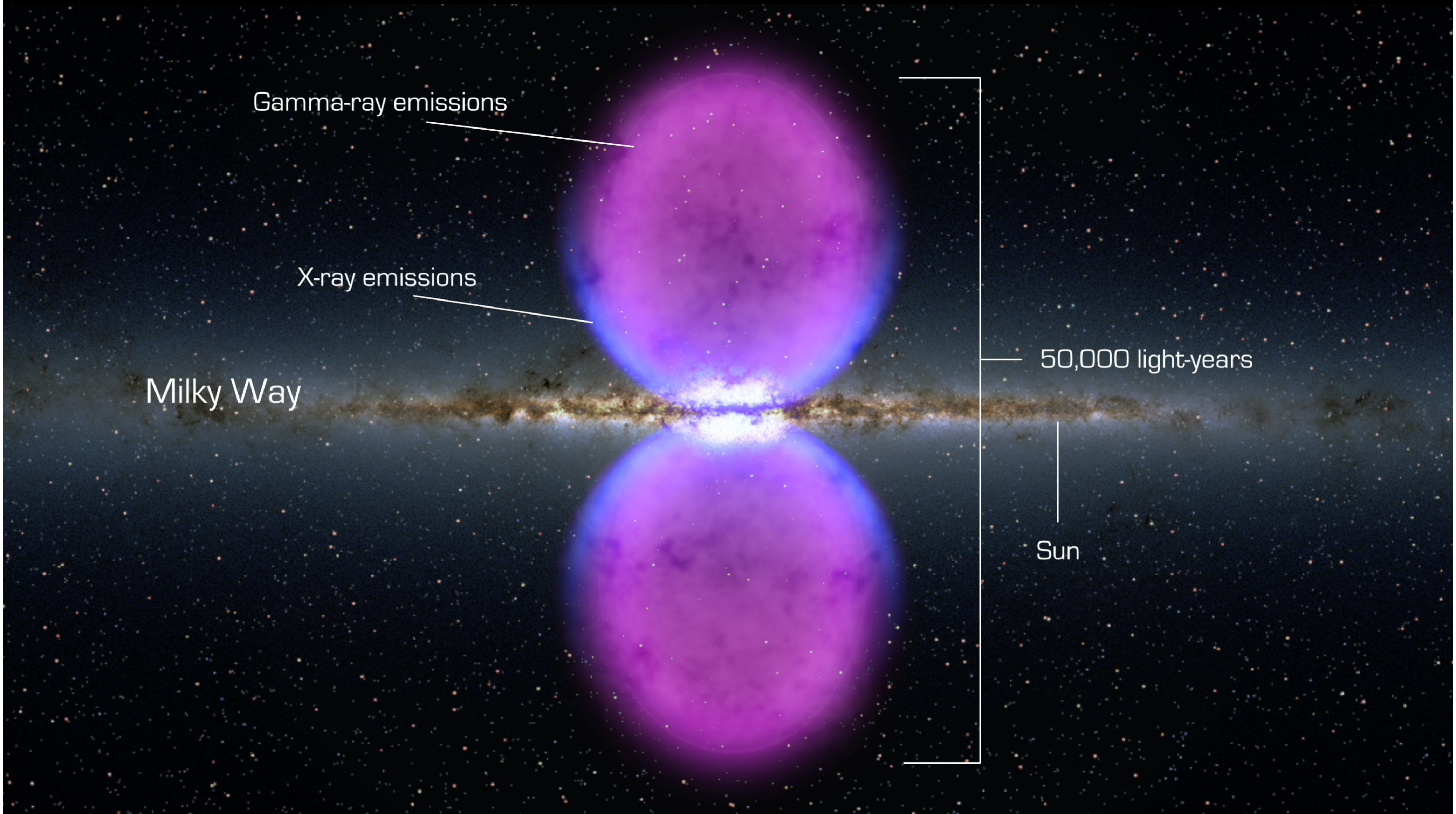
The gamma-ray sky from LAT scanning data



The Gamma-ray Sky above 1 Billion Electron Volts (1 GeV)

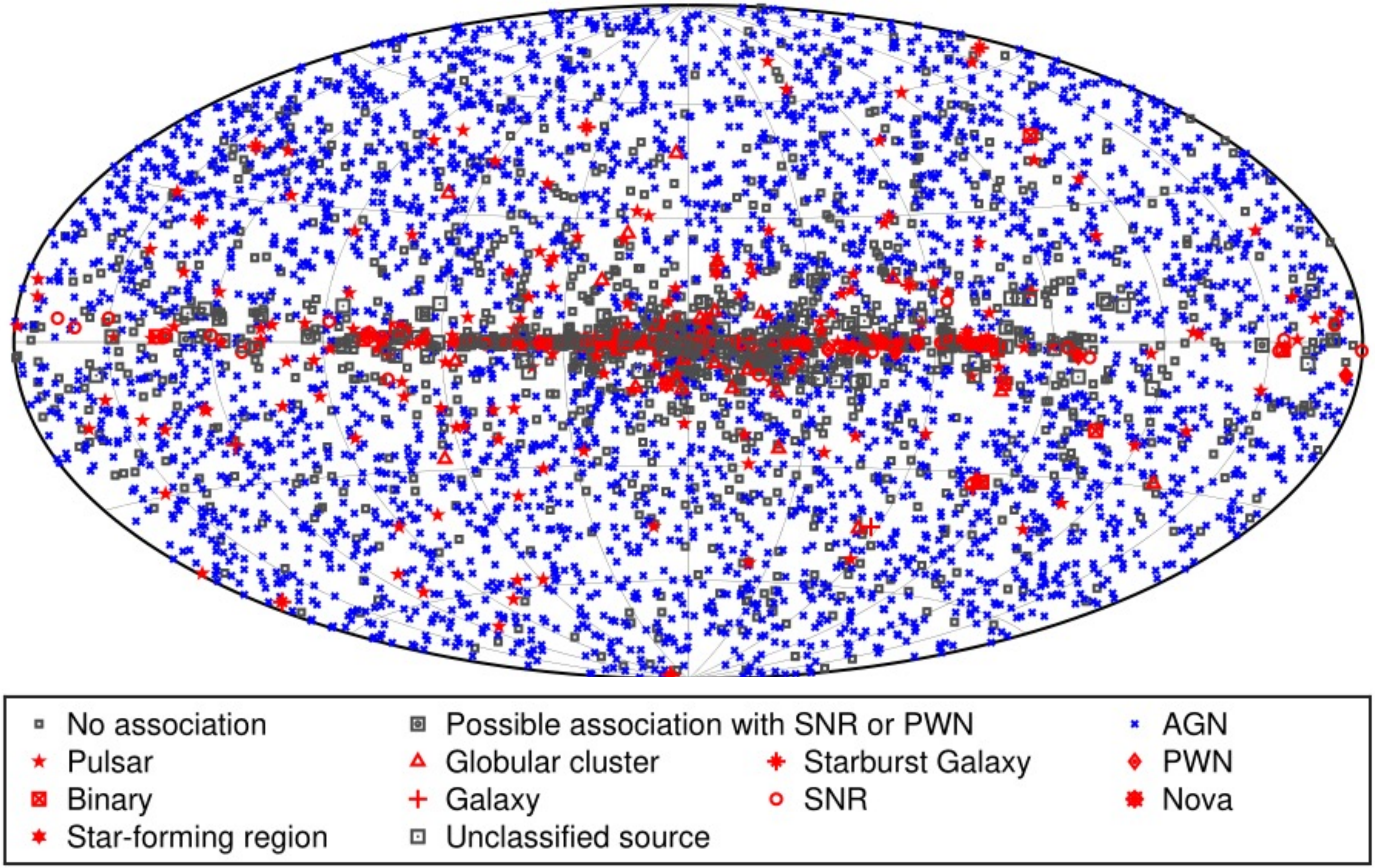
The Gamma-ray Sky above 10 Billion Electron Volts (1 GeV)



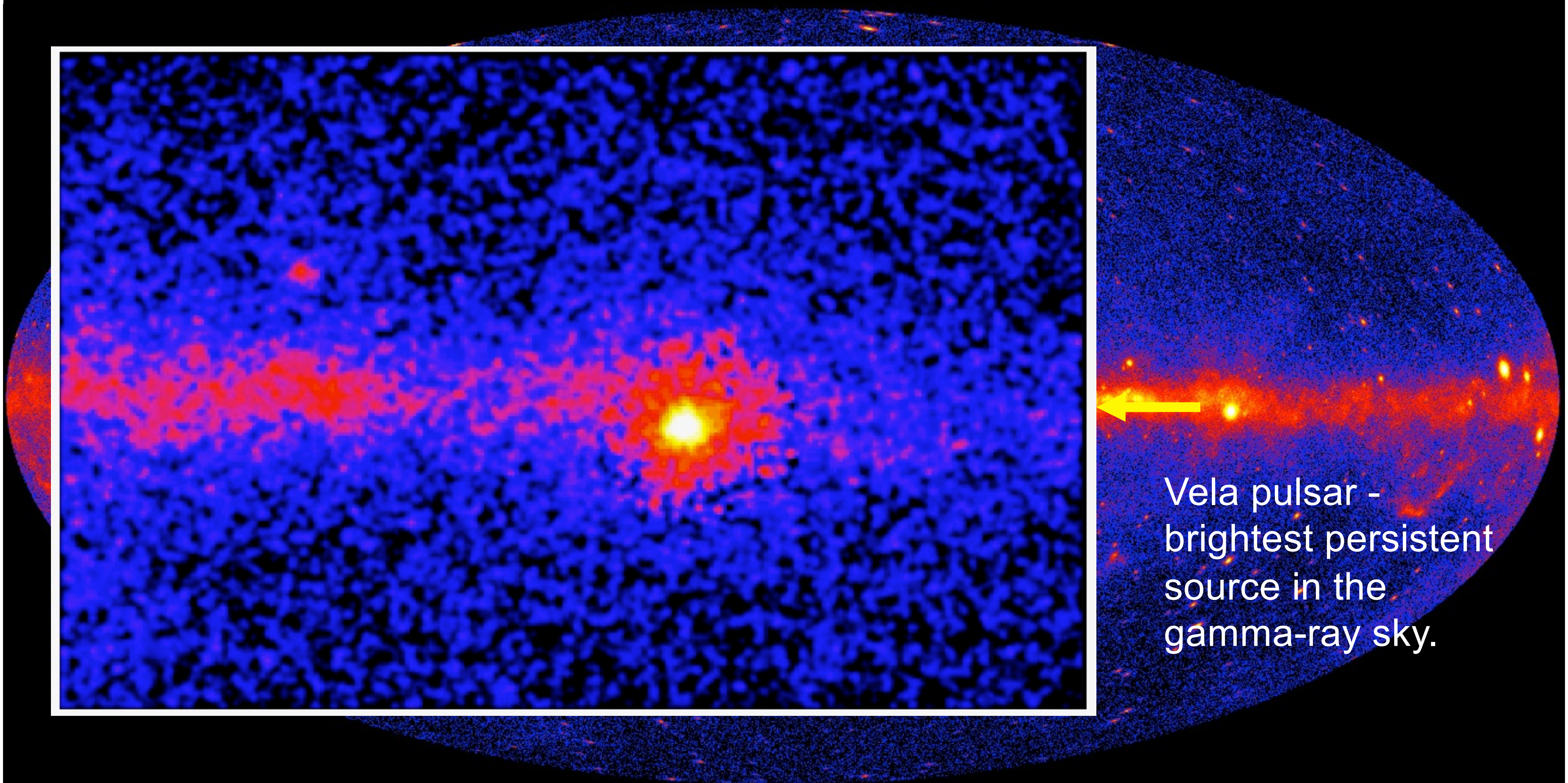


These "Fermi bubbles" may indicate past energetic activity in the center of our Galaxy.

The Fourth Fermi-LAT Catalog – over 5000 sources



Pulsars - rapidly rotating neutron stars



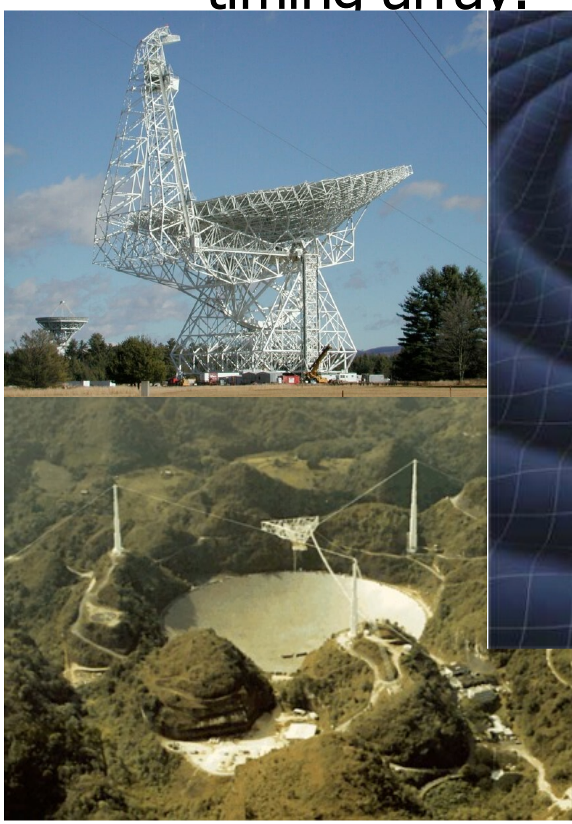
The actual rotation of the star takes less than 1/10 second.

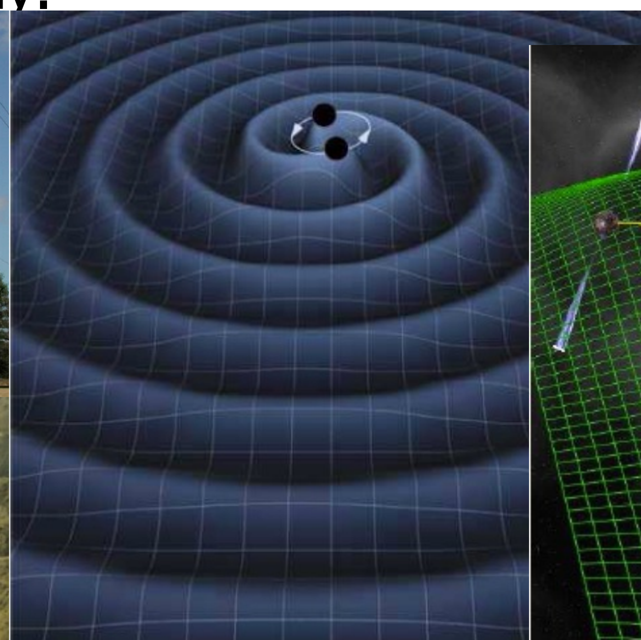
What Are We Learning about Pulsars?

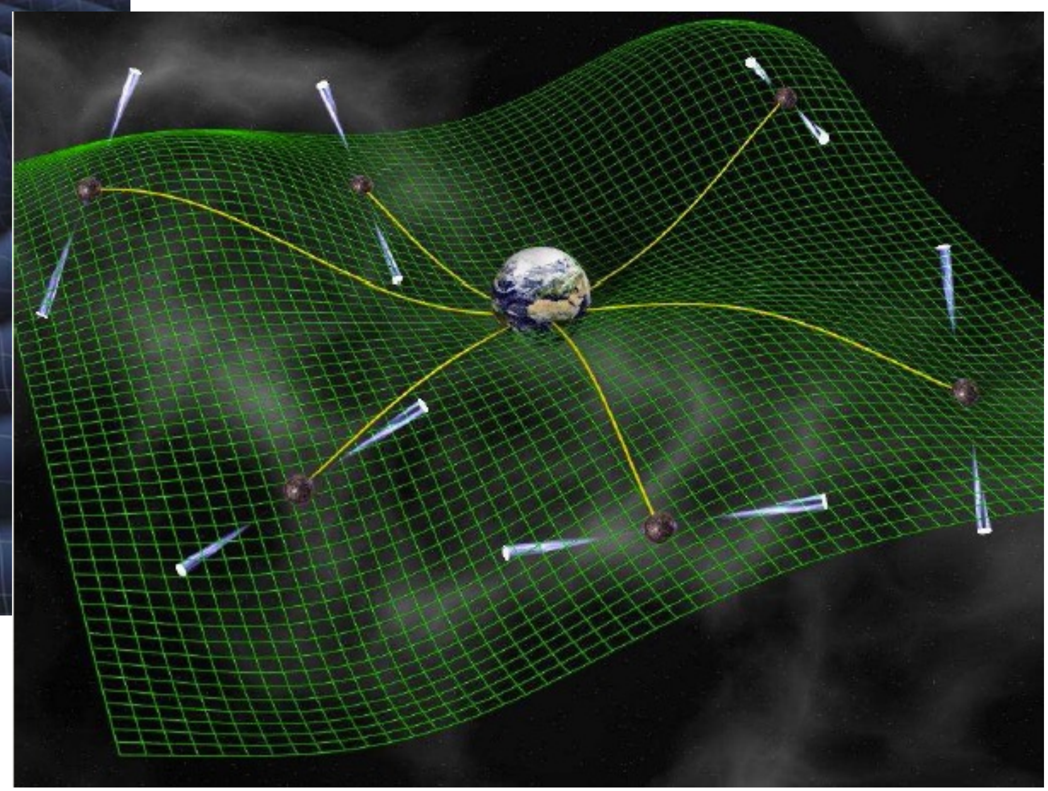
- About 1/3 of the Fermi pulsars are seen only in gamma rays. The gamma rays are being produced in a wide beam far from the neutron star surface, unlike radio pulsar emission.
- Old, “recycled” pulsars with millisecond periods can produce gamma rays in much the same way as younger pulsars.
- Close cooperation between radio and gamma-ray astronomers has produced new pulsar discoveries at both ends of the electromagnetic spectrum, including finding over 40 new millisecond pulsars, which are extremely accurate “clocks.”

Pulsar Timing Arrays as Gravitational Wave Detectors

- Radio telescopes can time millisecond pulsars to 100 nanoseconds
- Arrays of MSPs can be sensitive to nHz gravitational waves – need 20-40 MSPs for detection in 5 years
- Search for stochastic gravitational wave background from black hole/galaxy mergers
- We now have enough gamma-ray pulsars to form an independent timing array.





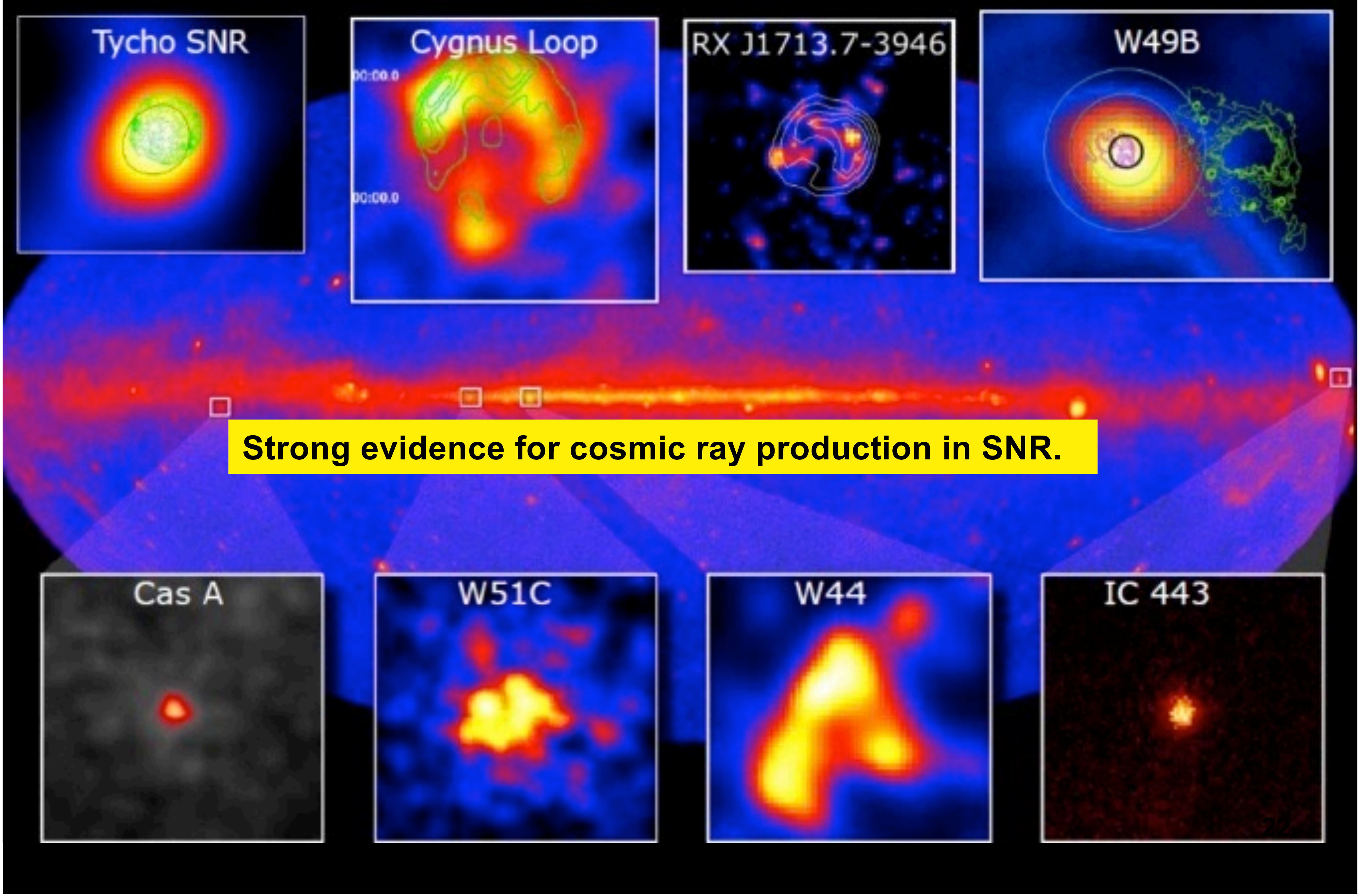


Join the Search for Gamma-ray Pulsars

Some of the same search techniques that have discovered gamma-ray pulsars in the Fermi LAT data are now available on home computers, using computer processing cycles when other activities are not in progress. **https://einsteinathome.org/**

The Einstein@Home project processes Fermi LAT data, as well as LIGO and radio astronomy data.

Supernova Remnants - Spatially Resolved

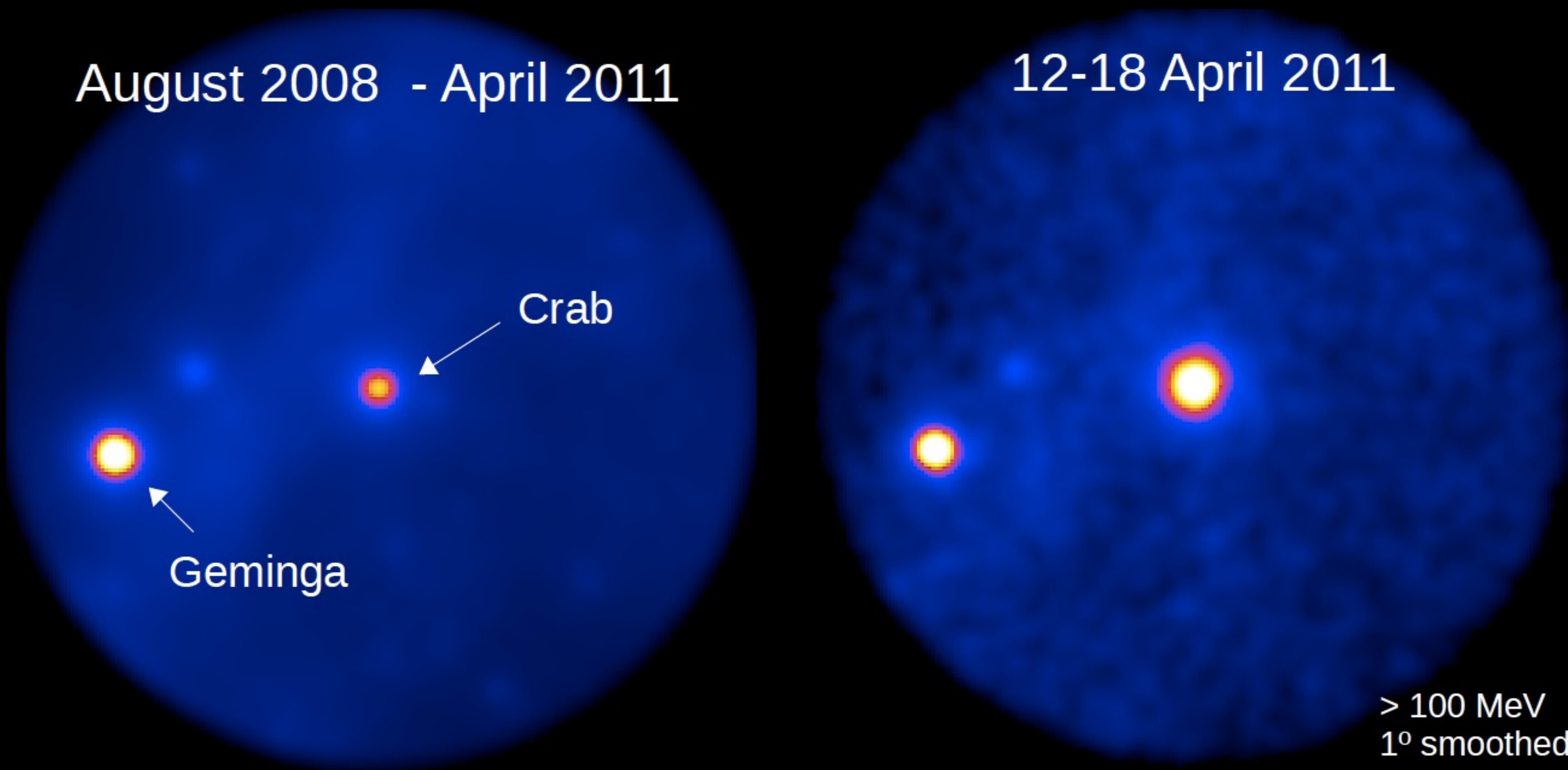


Strong evidence for cosmic ray production in SNR.

The Crab Nebula - A Rosetta Stone of Astrophysics

Supernova seen in 1054 $\rightarrow$ Supernova remnant and pulsar

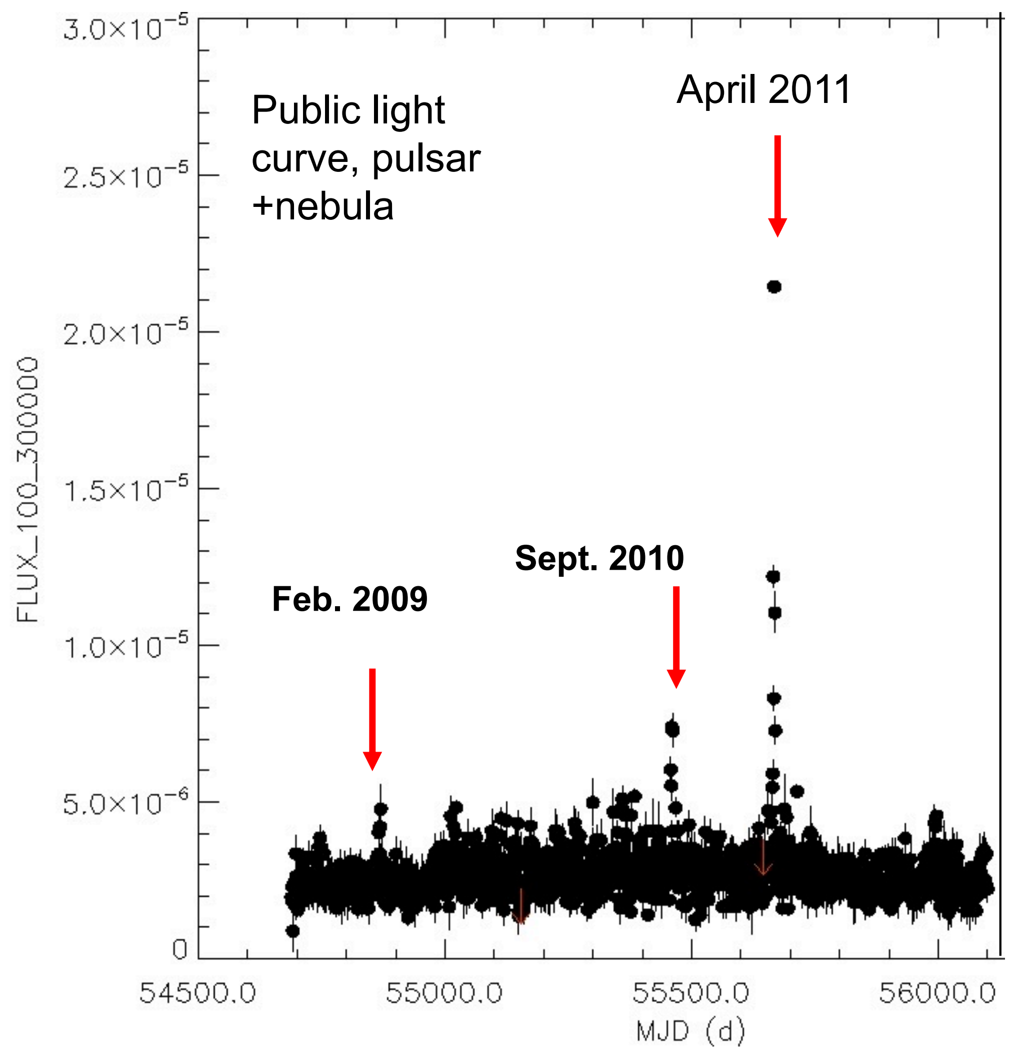
Crab Flares (>100 MeV)



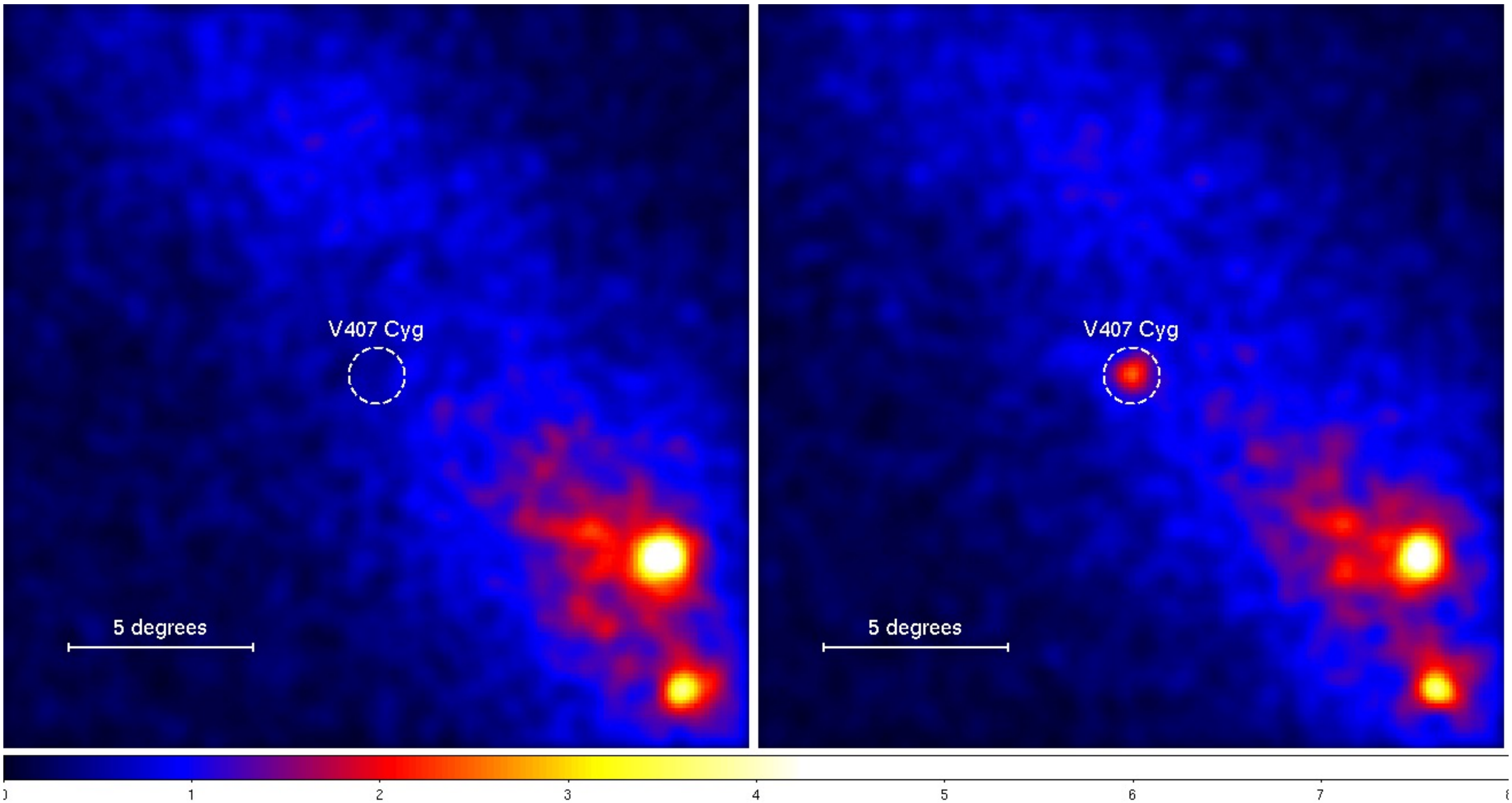
The "steady" Crab Nebula is not steady in gamma rays.

Crab Gamma-Ray Brightness

- **Shockingly bright flares in Sept 2010 and April 2011.**
- **Rapid identification of flares by LAT team enabled Chandra and Hubble Target of Opportunity observations in Sept, and sequence of Chandra observations in April (target visibility issues for Hubble)**
- **Rapid (hourscale) variability of PeV electrons poses severe challenges for acceleration mechanisms**



March 2010 - a Galactic plane transient



When we looked at the Swift webpage to request X-ray observations, we noticed that Swift was already looking at this location!

A Surprise - A Gamma-ray Nova

Electronic Telegram No. 2199

Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
CBAT Director: Daniel W. E. Green; Room 209; Dept. of Earth and Planetary
Sciences; Harvard University; 20 Oxford St.; Cambridge, MA 02138; U.S.A.
e-mail: cbat@iau.org; cbatiau@eps.harvard.edu
URL http://www.cfa.harvard.edu/iau/cbat.html

V407 CYGNI

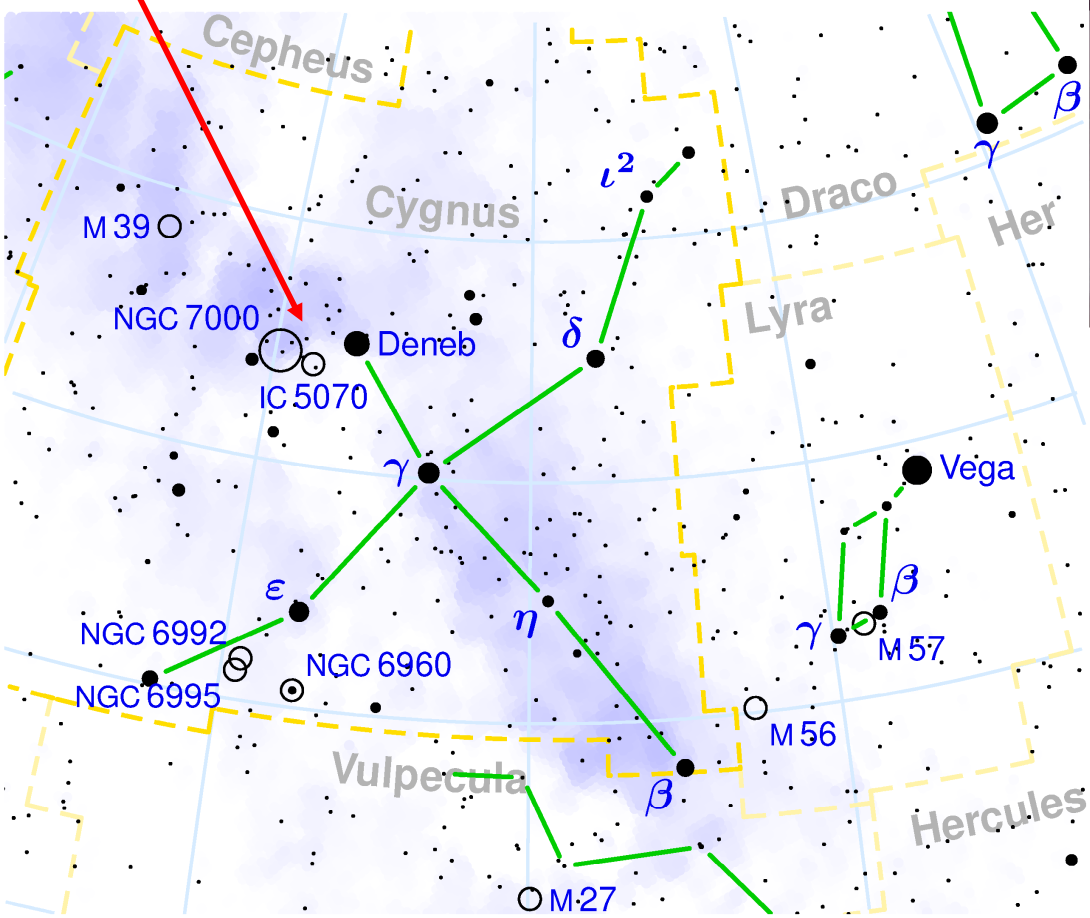
Hiroyuki Maehara, Kwasan Observatory, Kyoto University, reports the
discovery by Koichi Nishiyama (Fukuoka, Japan) and Fujio Kabashima (Saga,
Japan) of an apparent unusually bright outburst (mag 7.4) of the symbiotic
star V407 Cyg on an unfiltered CCD image ... a
105-mm camera lens (+ SBIG STL6303E came...
confirmed the outburst on two unfiltered ... 3 (at
mag 6.8) and 10.814 (mag 6.9) using a 0. ...

The amateur astronomers who
discovered the optical flare.

V407 Cygni: a binary system

Symbiotic binary:
small white dwarf star and large red giant star orbiting each other closely

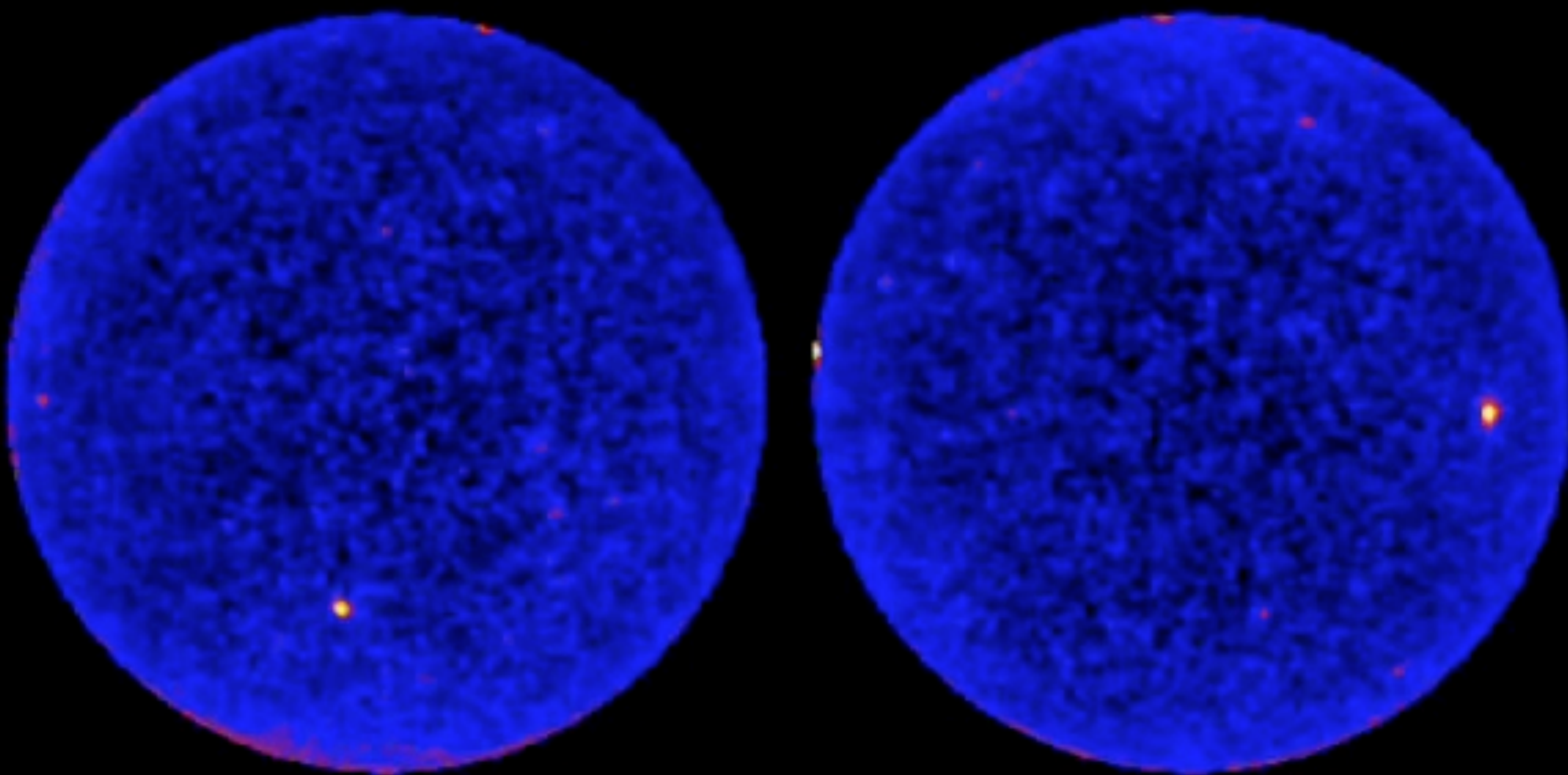
Near Deneb in Cygnus



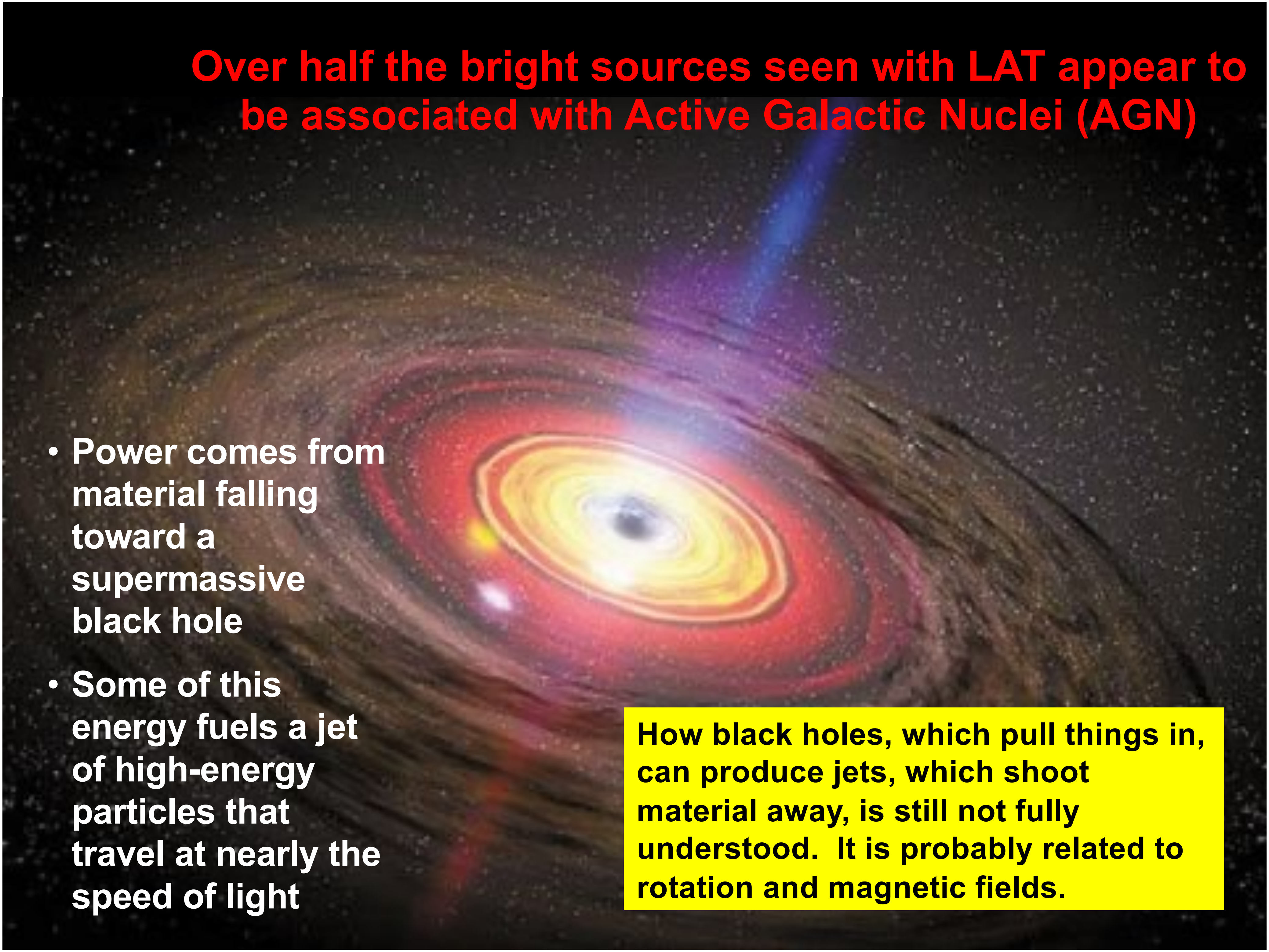
The shock wave from the nova thermonuclear explosion accelerates particles that interact with the surrounding material to produce the gamma rays.

V407 *Cyg* ~ 6000 light years away

The Variable Gamma-ray Sky



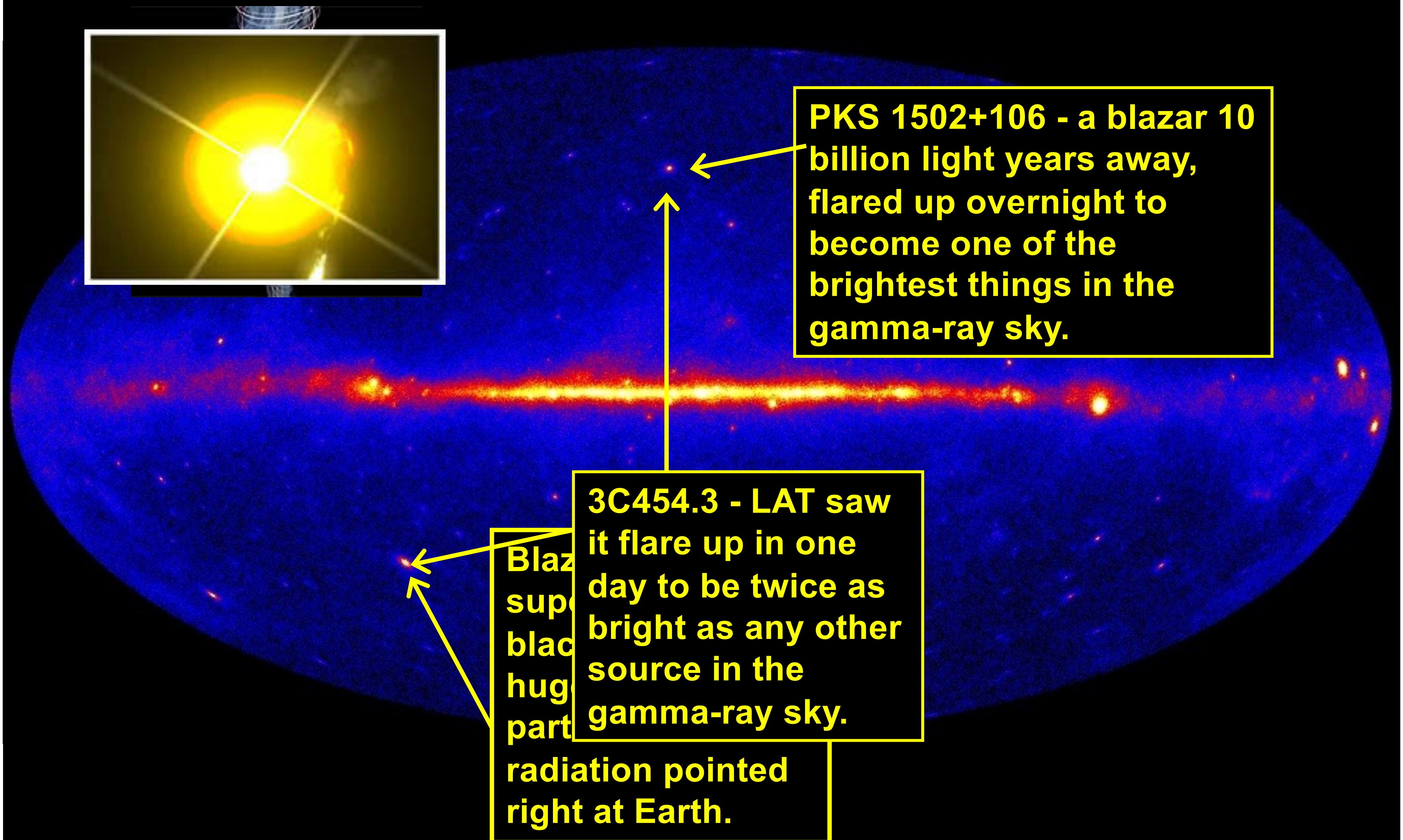
Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)



- Power comes from material falling toward a supermassive black hole
- Some of this energy fuels a jet of high-energy particles that travel at nearly the speed of light

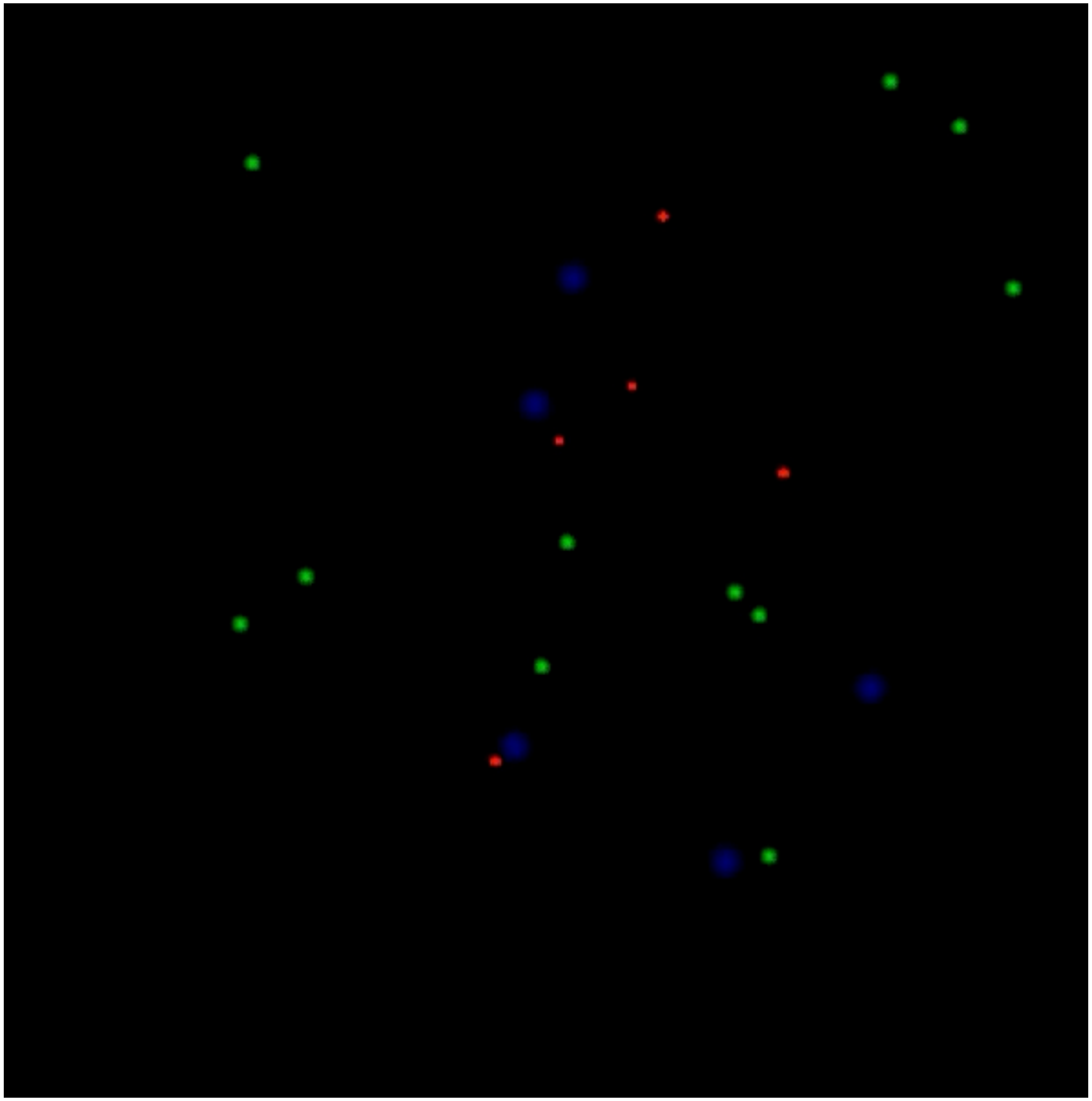
How black holes, which pull things in, can produce jets, which shoot material away, is still not fully understood. It is probably related to rotation and magnetic fields.

Gamma rays from blazars



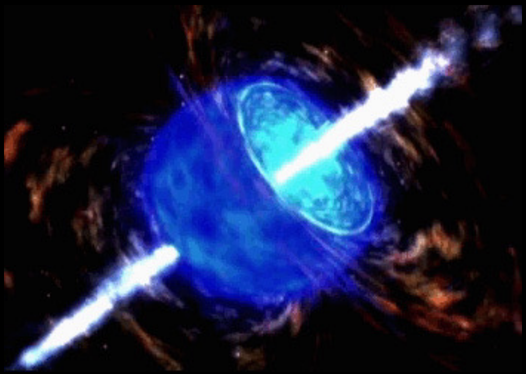
Blazars can help trace the history of starlight

Gamma-Ray Bursts (GRBs): the most powerful explosions since the Big Bang



- Originally discovered by military satellites, GRBs are flashes of gamma rays lasting a fraction of a second to a few minutes.
- Optical afterglows reveal that many of these are at cosmological distances
- The GBM and LAT extend the energy range for studies of gamma-ray bursts to higher energies, complementing Swift and other telescopes.
- Fermi is helping learn how these tremendous explosions work.

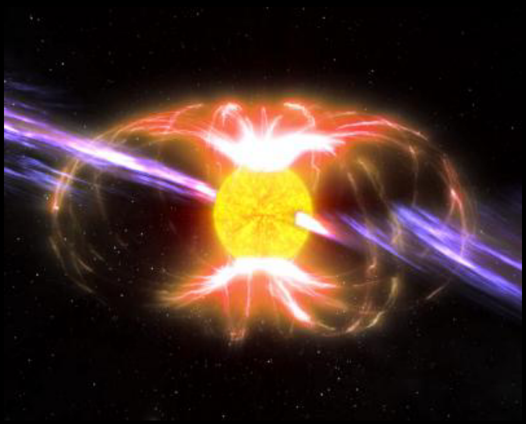
Gamma-ray bursts come in at least three flavors



Collapsars: A rapidly spinning stellar core collapses and produces a supernova, along with relativistic jets that can produce long GRBs

Compact Mergers: Two neutron stars, or a neutron star and a black hole, collide and merge, producing a jet that gives rise to a short GRB

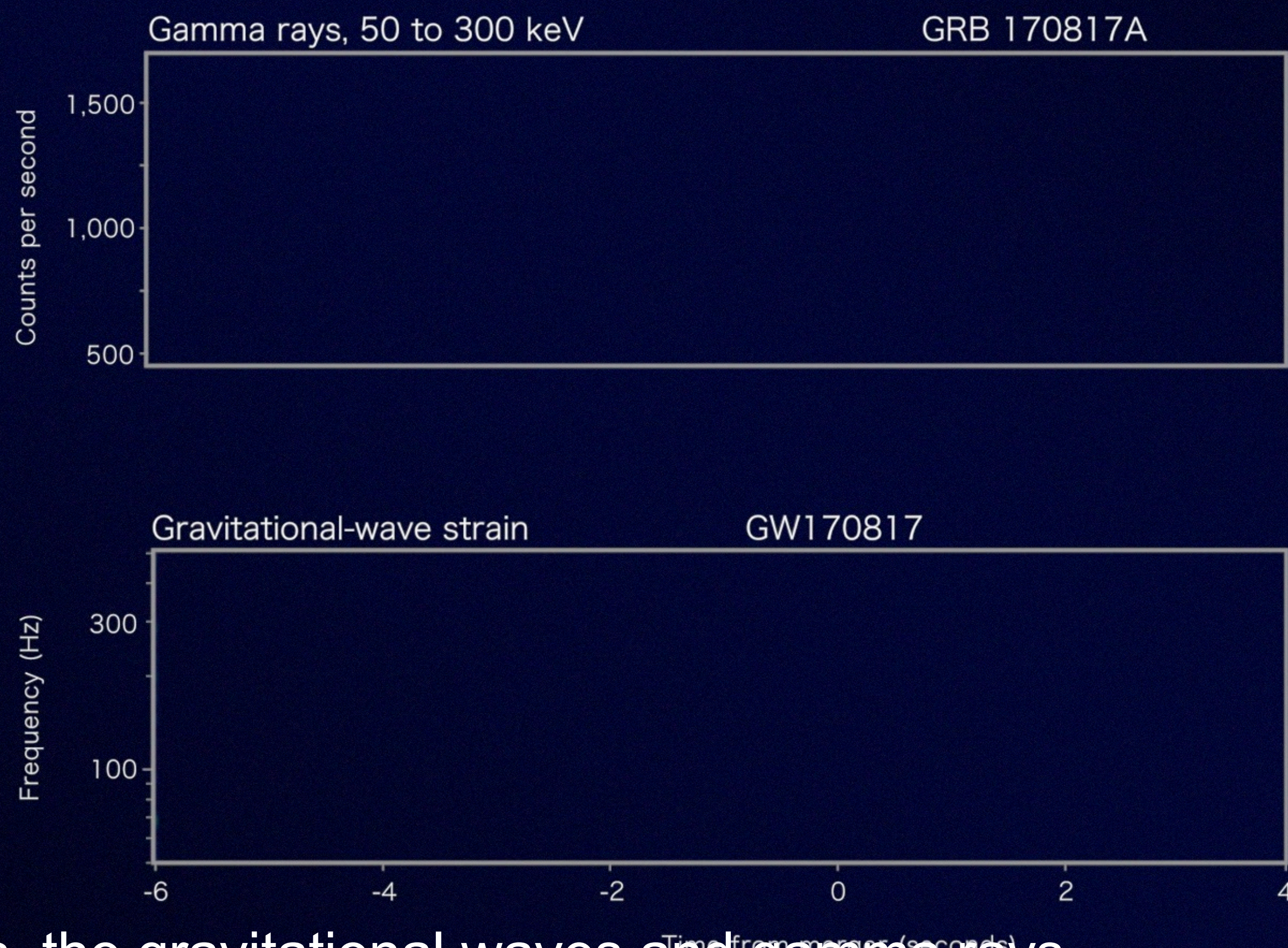
In both these cases, the burst probably produces a black hole.



Magnetars: Neutron stars in our Galaxy or nearby galaxies with extremely strong magnetic fields can give off powerful bursts that resemble short GRBs

Gravitational waves and gamma rays from merging neutron stars

Fermi



LIGO

After 130 million years, the gravitational waves and gamma rays arrived within 2 seconds, implying that the speed of gravity is almost identical to the speed of light.

Testing Einstein’s Theory of Special Relativity

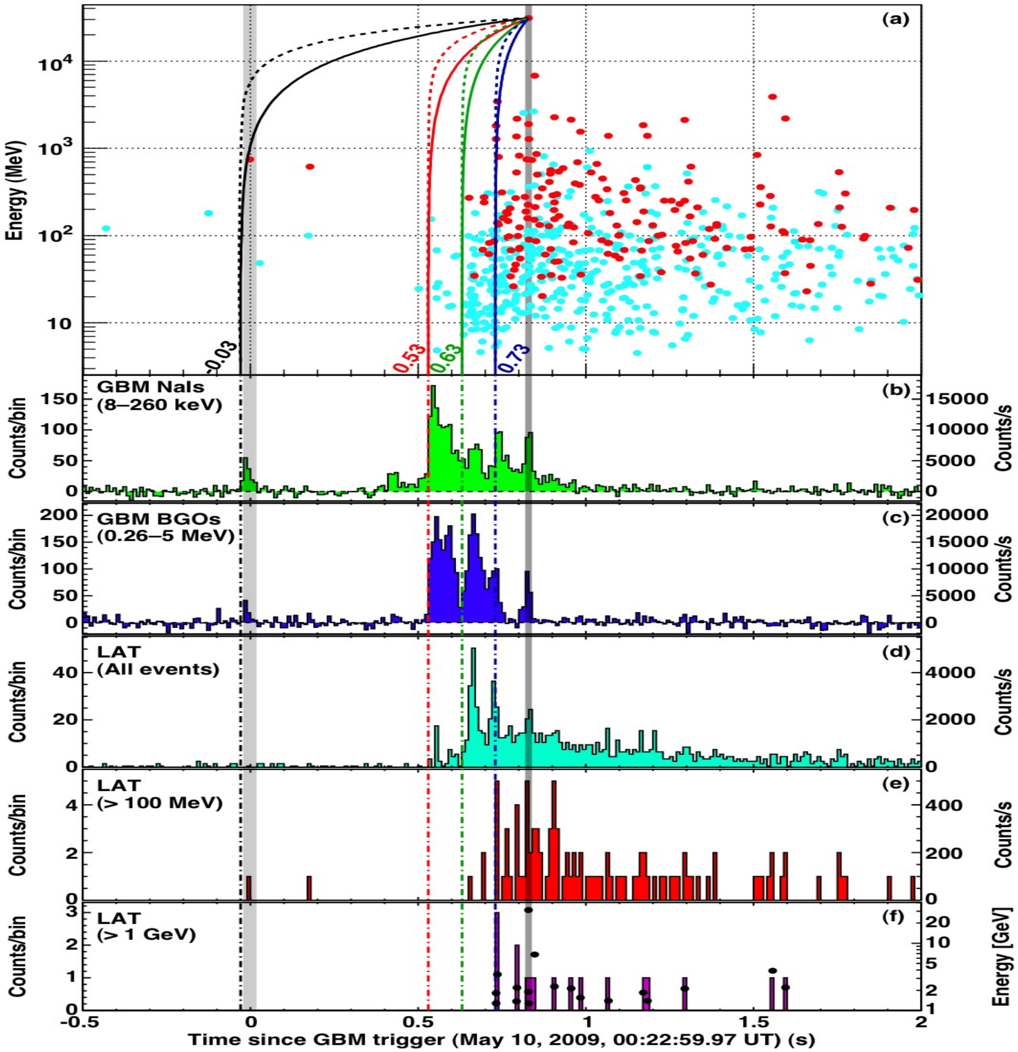
- The Principle of Invariant Light Speed – *Light in vacuum propagates with the speed c (a fixed constant), regardless of the state of motion of the light source.*

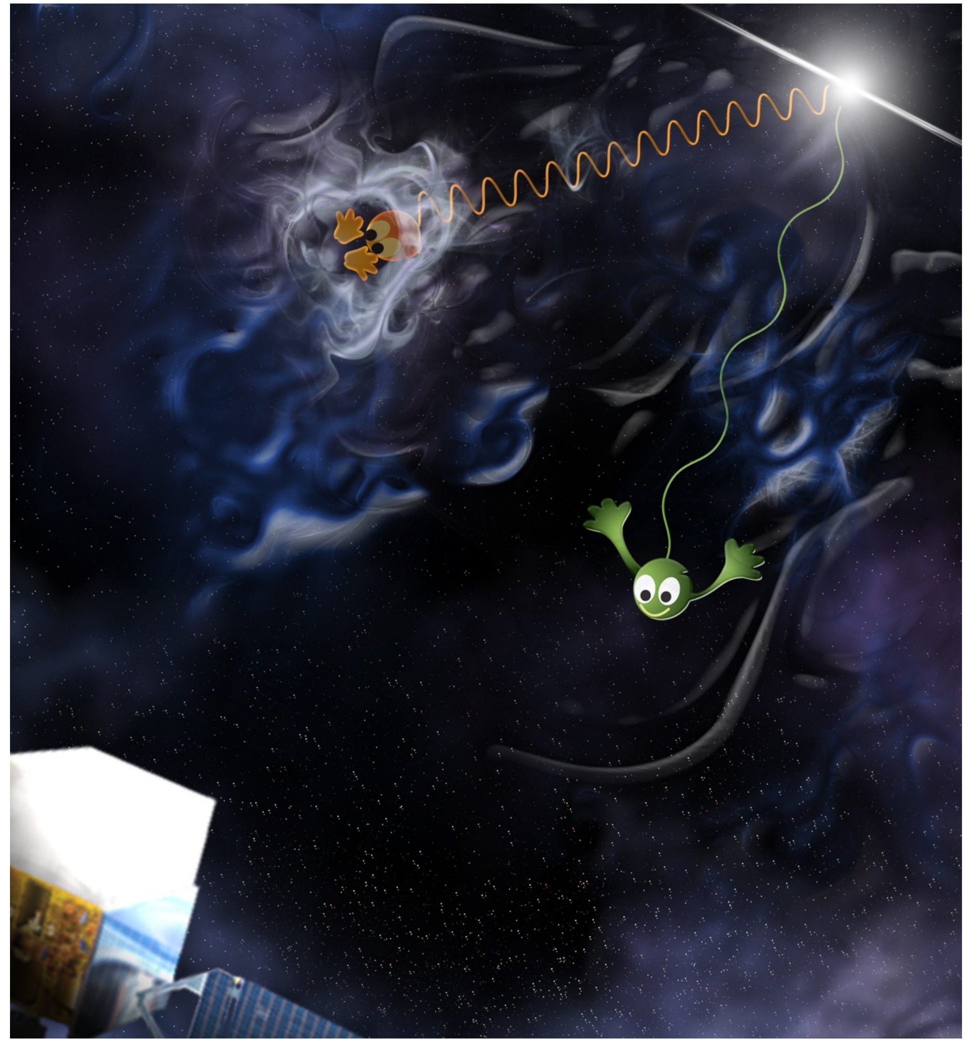
- Some models of Quantum Gravity challenge Einstein’s idea, predicting that not all photons travel at the same speed; “foamy” space-time might slow down higher-energy photons.

- Consider a race between two photons traveling a very large distance at slightly different speeds. The slower photon will arrive later.
  - To do this we need
    - Distant object
    - Very bright
    - Well defined start time

- **This is where Gamma-ray Bursts come in.**

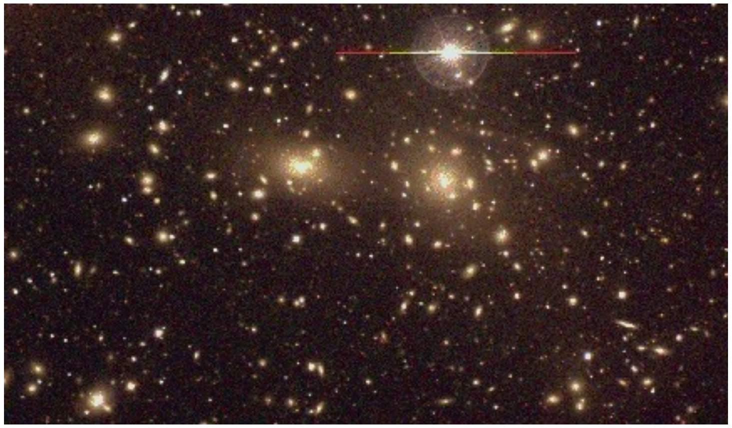
GRB 090510 - testing models of Quantum Gravity





Highest energy gamma-ray arrived within 0.9s of the lower energy photons after traveling 7 billion years.
Eliminates theories of quantum gravity that predict space-time is "foamy" enough to interfere strongly with light.

What is Not Seen Can Also Be Important



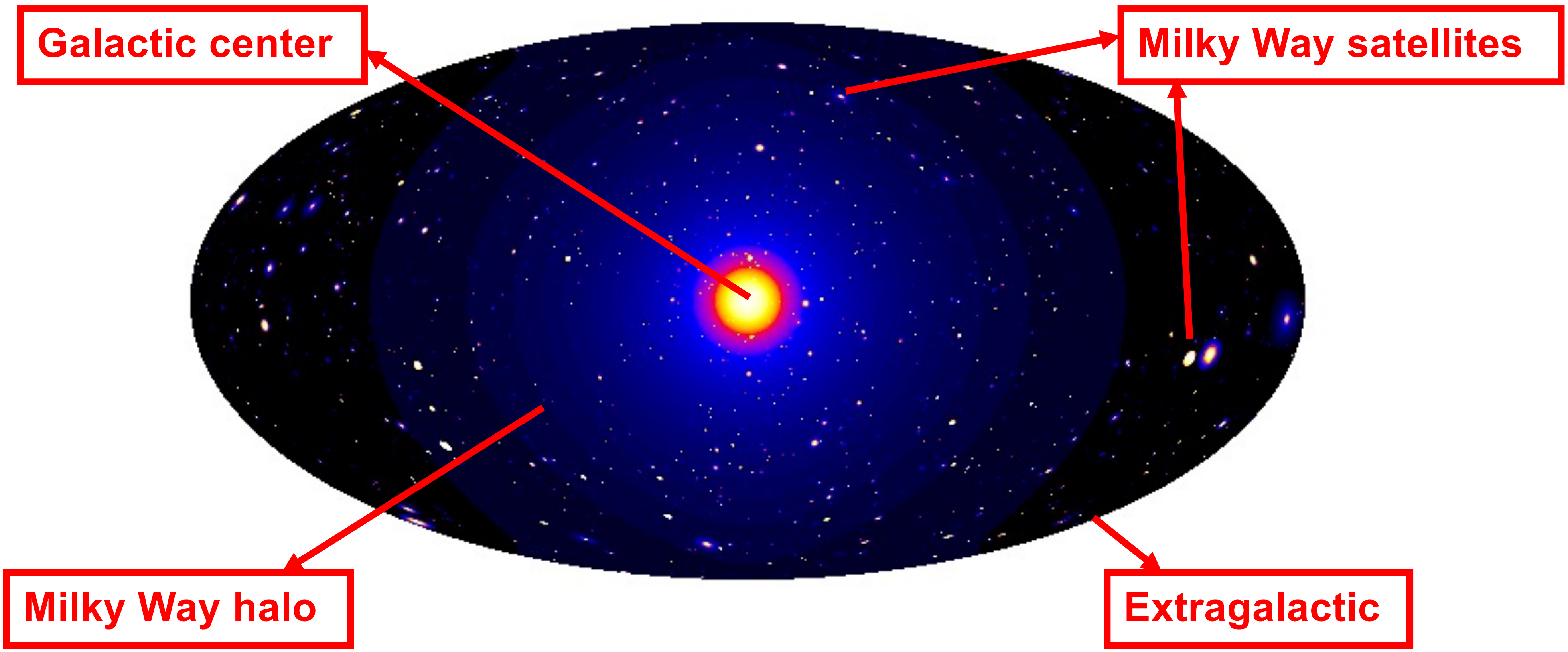
Some clusters of galaxies were predicted to be gamma-ray sources. None are seen in the LAT Catalog, indicating that the predictions were too optimistic.

Dwarf spheroidal galaxies are thought to be largely composed of dark matter. If dark matter consists of some types of Weakly Interacting Massive Particles (WIMPs), such galaxies would be gamma-ray sources visible to Fermi LAT. Their absence puts constraints on dark matter models.

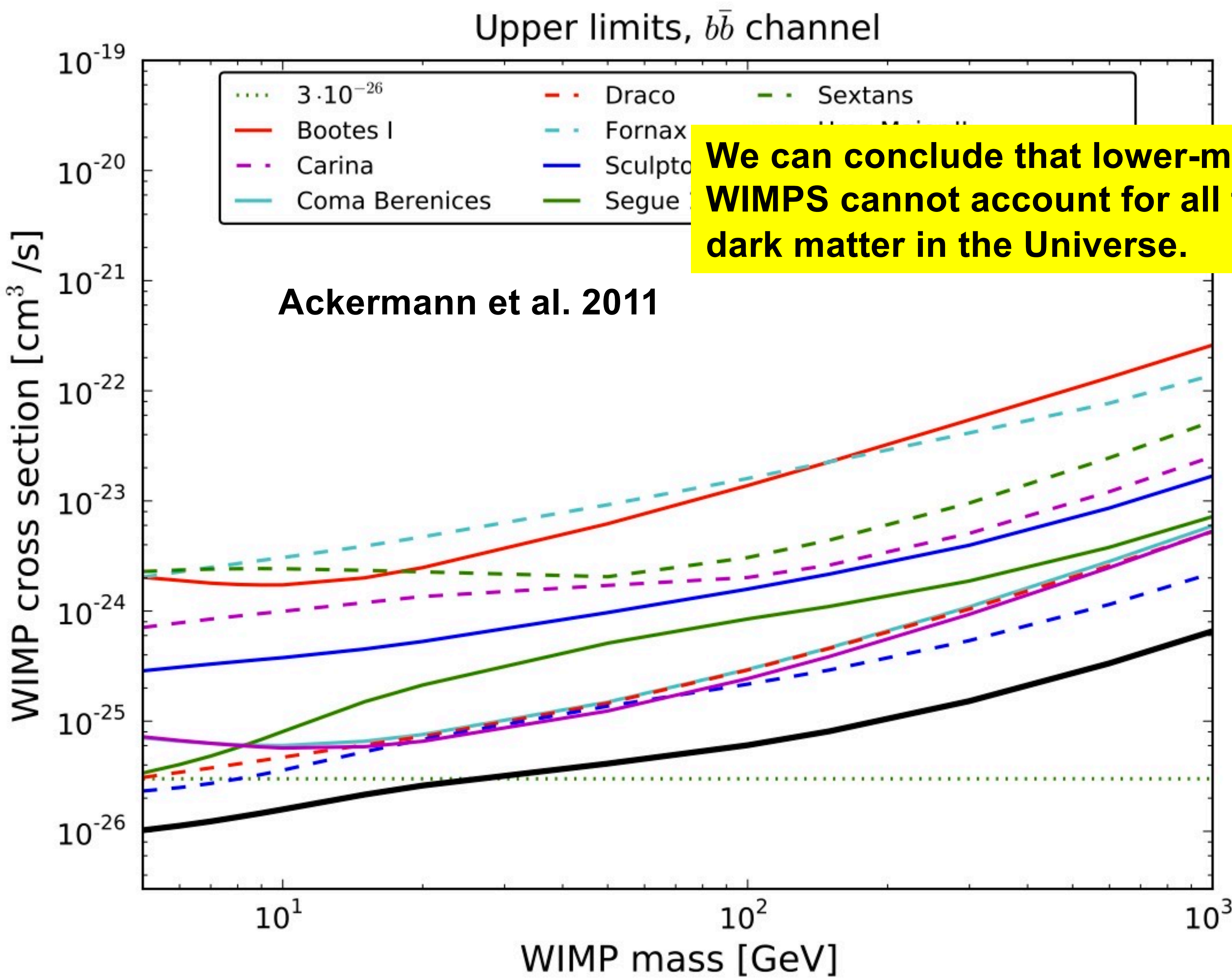
DM (only) in the gamma ray sky - Predicted

Milky Way Halo simulated by Taylor & Babul (2005)

All-sky map of DM gamma ray emission (Baltz 2006)



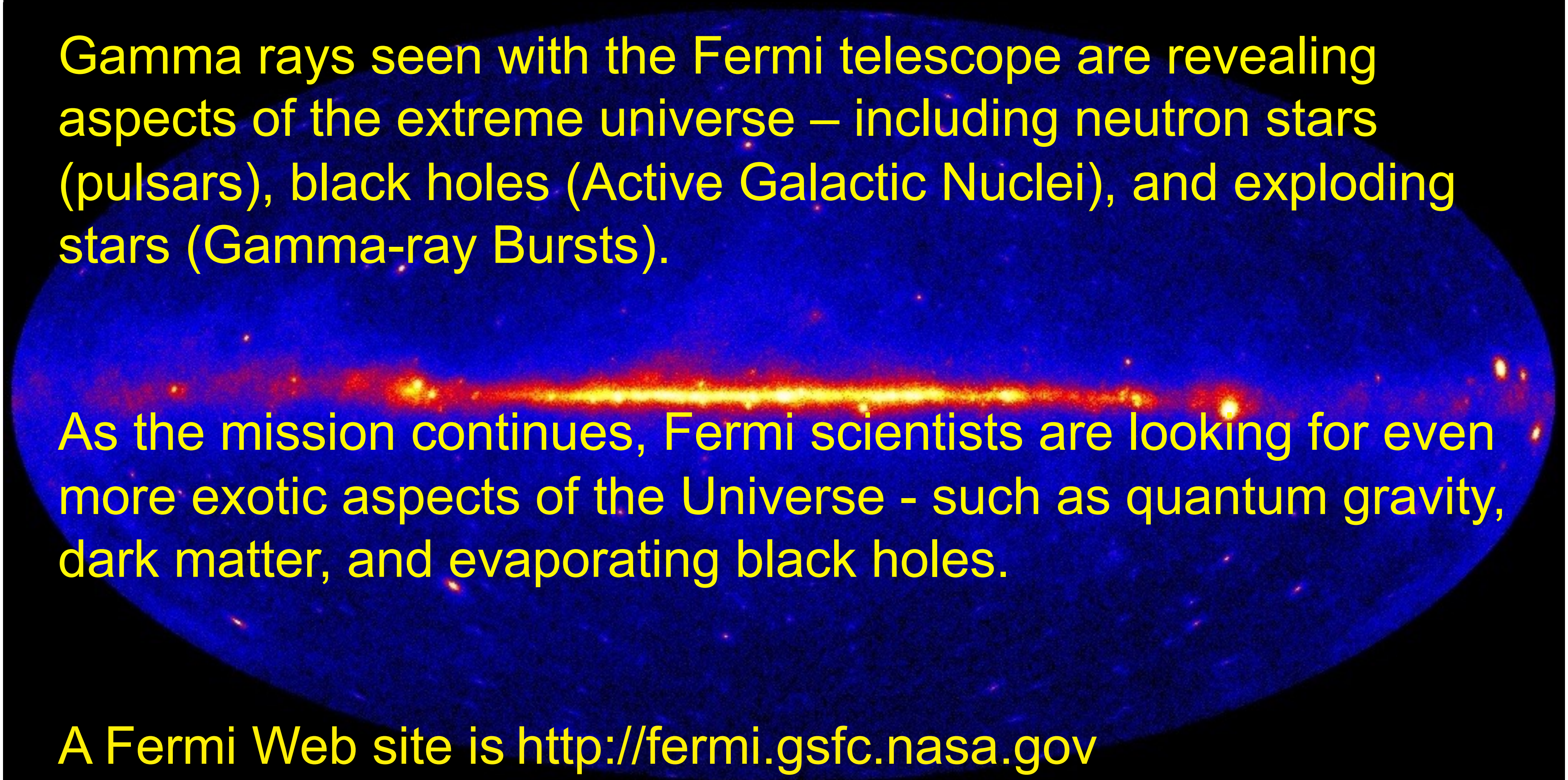
Fermi LAT Constraints on Dark Matter



We can conclude that lower-mass WIMPS cannot account for all the dark matter in the Universe.

Thermal limit

Summary - the Extreme Universe



Gamma rays seen with the Fermi telescope are revealing aspects of the extreme universe – including neutron stars (pulsars), black holes (Active Galactic Nuclei), and exploding stars (Gamma-ray Bursts).

As the mission continues, Fermi scientists are looking for even more exotic aspects of the Universe - such as quantum gravity, dark matter, and evaporating black holes.

A Fermi Web site is http://fermi.gsfc.nasa.gov

All the Fermi gamma-ray data are public. Join the fun!